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Effects of Endurance Fitness on Responses to Cold Water Immersion

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The purpose of this study was to determine if the changes in selected blood hormones and substrates, metabolic rate, and rectal temperature (T_{re}) in nine males after immersion in 10°C water, while clad in standard flight suits, were related to the level of aerobic fitness. Fitness was evaluated by the blood lactate response to submaximal exercise. Immersion time (IT) was defined as the time required for a 1°C decrease in T_{re} and averaged 38.5 (range: 21–62) min. Metabolic rate increased 3.4 times the resting rate. Lactate, free fatty acids, triiodothyronine and thyroxine increased by 81%, 38%, 11%, and 8%, respectively, in contrast to insulin which decreased by 32%, with all changes being statistically significant ($p<0.05$). Glucagon increased slightly but not significantly ($p=0.11$) while glucose levels did not change. The IT was correlated directly with a measure of aerobic fitness, with relative body fat, and with the T_3 levels postimmersion ($p<0.05$). The results suggest that the aerobic fitness level can significantly influence the cooling rate during water immersion.

THE HUMAN PHYSIOLOGIC response to acute cold water immersion is multi-faceted and includes hormonal and metabolic changes which are directly related to the degree of thermal stress (15,16). The changes are similar to those which occur during submaximal exercise (14,15). Since physically well-trained individuals demonstrate smaller hormonal changes than do untrained subjects during submaximal exercise (2), we hypothesized that a similar effect of training may occur during cold water immersion, i.e. a high level of aerobic fitness would be associated with diminished hormonal and metabolic changes induced by the cold exposure. These changes might result in a decreased rate of body cooling. While some previous studies have demonstrated increased cold tolerance after physical training, others show no effect (for review see ref. 17), and the issue is far from resolved. The purpose of the present study was to clarify the relevance of the aerobic fitness level by evaluating the endurance exercise capacity of the subjects and relating this to their metabolic and hormonal responses to the cold water immersion.

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MATERIALS AND METHODS

Nine healthy males volunteered to participate as subjects. They were fully informed, prior to testing, of the details of the experimental protocol and any associated risks or discomforts. None of the subjects had previous cold water immersion experience.

Subjects' Physical Characteristics: One week prior to the cold water immersion the subjects reported to the laboratory. Height and weight were recorded and body surface area (BSA) calculated (11). Percent body fat was calculated after determination of body density by hydrostatic weighing (3), with residual volume measured by the nitrogen washout technique using a Hewlett Packard 47804S Pulmonary Testing System.

Aerobic Fitness: Aerobic fitness was evaluated by having all subjects perform 4 min acute exercise on an electrically-braked cycle ergometer (Collins Pedalmate) at 70 rev·min^{-1} with a constant power output of 200 W. Blood was sampled (100 µl) from the finger-tip immediately after exercise and assayed for lactate (32). A validation of the specific protocol used to evaluate the aerobic component of physical fitness in the present study is described in detail elsewhere (20). The choice of this method of fitness evaluation, in contrast to the measurement of the subjects' maximal oxygen consumption ($\dot{V}o_{2\ max}$), was based on several recent studies which demonstrated that the capacity for endurance ex-

ercise is more closely related to blood lactate related variables than to $\dot{V}O_{2max}$ (12,22,26).

Cold Water Immersion: All subjects reported to the laboratory at least 2 h after a light breakfast. Subjects were asked to refrain from consuming coffee or tea on the morning of immersion. A rectal probe (YSI model 401) was inserted 15 cm beyond the anal sphincter. The subject donned standard Canadian Forces flying clothing consisting of the following items: 100% wool socks, 100% cotton long underwear, 100% cotton turtleneck shirt, leather flying boots, 60% polyester and 40% wool flying coverall, leather flying gloves with a knitted wool insert. Subjects then sat quietly for 15 min at an ambient temperature of 21°C. Open circuit spirometric methods were used to calculate the oxygen uptake at rest. A maritime aircrew life preserver was placed uninflated over the subject's head and tied in place. The subject then lowered himself into the water tank 2.5×2.5×3 m, which was controlled at 10°C. A constant flow of air was bubbled through the water at all times to facilitate adequate water mixing. Immediately upon entering the water the entire head was submerged for a few seconds after which the life preserver was inflated. The subjects remained in a semi-supine position, easily maintained without exertion because of the life preserver, with hands held below the water surface. Rectal temperature (T_{re}) was automatically recorded and printed every min with a Hewlett-Packard 3052A data acquisition system. Expired gases were collected in Douglas bags for 3–4 min every 10th min during immersion. The volume of expired air was determined with a wet spirometer (Collins 350 l gasometer) and the concentrations of oxygen and carbon dioxide were analyzed with Applied Electrochemistry SA-3 and Beckman LB-2 analysers, respectively. Venous blood was sampled with stasis from a prominent ante-cubital vein with Vacutainers (Becton Dickinson) containing proper additives immediately prior to and within 3 min following the water immersion. The blood was assayed for serum free fatty acids (FFA) (36), plasma glucose and lactate (32), serum insulin (31), plasma glucagon (29), serum total triiodothyronine (T_3) (6) and serum thyroxine (T_4) (7).

The total immersion time was defined as the time until rectal temperature decreased by 1°C from the temperature recorded just prior to immersion. This criterion was chosen after consideration of the rectal temperature decrease likely to occur after the immersion during the initial phases of rewarming, and in light of guidelines imposed by the Institution's Human Ethics Committee.

Statistical Methods: The Biomedical Computer Programs (8) statistical package was used for all analyses. Missing data points were not replaced by computed dummy variables. Student's *t*-test for paired observations was used to calculate the significance of differences between mean pre- and postimmersion concentrations of the blood variables. The level of statistical significance was set at 0.05.

RESULTS

The mean time required for a 1°C decrease in T_{re} w. (mean ± S.D.) 38.5 ± 13.1 min and ranged from 21–62 min.

TABLE I. SOME PHYSICAL CHARACTERISTICS OF THE PARTICIPATING SUBJECTS.

	Age (yr)	Weight (kg)	Height (cm)	BSA (m^2)	Body Fat (%)
Mean	30.3	76.6	177	1.934	16.5
S.D.	5.7	5.4	6.7	0.10	6.5
Range	23–38	62–81	166–187	1.689–2.008	4–27

Some physical characteristics of the subjects are described in Table I. Total immersion time was directly related to relative body fat (Fig. 1).

The blood lactate concentrations after the 4 min of acute exercise at 200 W averaged 6.7 ± 2.1 mM and ranged from 3.1–9.7 mM. Since one subject was unable to complete 4 min of exercise at 200 W, his lactate value is not reported. There was an inverse relationship between total immersion time and the post exercise lactate level (Fig. 2).

Metabolic rate during the immersions (METS) was expressed as a multiple of the preimmersion oxygen uptake. The mean maximal change observed was 3.372 ± 1.09 METS. The values ranged from 1.969–5.110 METS. Neither the maximal change in metabolic rate nor the mean metabolic rate during the immersions were significantly related to total immersion time.

Table II lists the blood substrate and hormone levels before and after immersion. Cold-induced vasoconstriction led to difficulties in filling the required number of Vacutainers for the postimmersion blood samples in some cases, accounting for the varying number of subjects reported in Table II. The statistical analyses were only performed for those subjects with both pre- and postimmersion data. Lactate, FFA, T_3 and T_4 increased significantly by 81%, 38%, 11%, and 8% respectively. Insulin decreased significantly by 32%. Four of the five subjects for whom samples were available for the glucagon assay showed decreases after immersion. The average decrease for all subjects was 20% of the preimmersion value, although this failed to achieve statistical significance ($p = 0.11$). Glucose levels did not change significantly. Total immersion time was related to the T_3 levels postimmersion ($r = 0.86$, $p < 0.05$, Fig. 3). The T_3

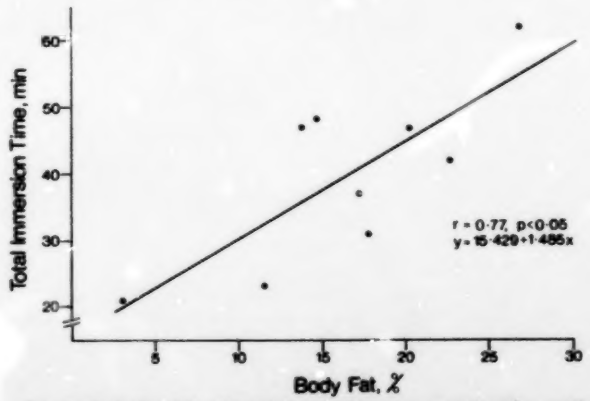

Fig. 1. Relationship of total immersion time required for a 1°C decrease in rectal temperature with percent body fat.

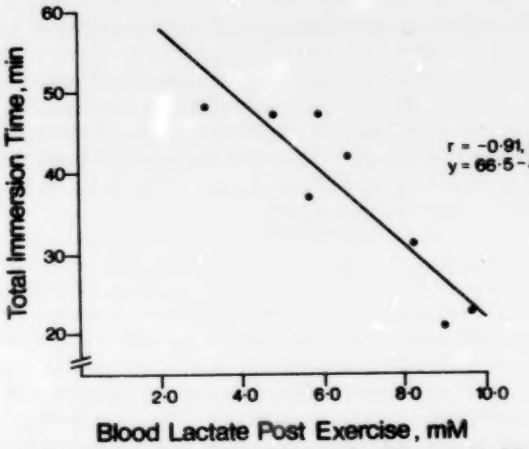

Fig. 2. Relationship of total immersion time required for a 1°C decrease in rectal temperature with blood lactate after cycling for 4 min at 200 W.

postimmersion concentrations were inversely related to the postexercise lactate values ($r = 0.90$, $p < 0.05$).

Since relative body fat was directly related to total immersion time, it may have influenced the relationship between immersion time and the postexercise lactate. This possibility was controlled by calculating the partial correlations between immersion time and the exercise lactate concentration, with relative body fat as the covariate. Statistically controlling the variation among subjects in percent body fat did not affect the significant relationship between immersion time and the postexercise lactate levels.

The possible influence of fitness level was further examined by dividing the subjects into "more fit" and "less fit" groups based on the median of the postexercise lactate values. Differences between groups in total immersion time, and changes in the blood variables were submitted to an analysis of covariance with percent body fat as the covariate. The more fit group demonstrated a significantly longer total immersion time ($p < 0.05$) than the less fit group although the between group differences were not significant for the blood variables.

DISCUSSION

A prime purpose of this investigation was to attempt to clarify the influence of the level of aerobic fitness on the response to cold exposure. For those readers not familiar with recent research associated with the prediction of endurance exercise performance, several studies have now been reported which demonstrate that blood lactate-related indices determined during submaximal exercise are more strongly correlated with endurance exercise performance than is the direct or indirect determination of maximal aerobic power (12,22,26). It has been demonstrated previously that blood lactate levels 4, 5 or 6 min after the onset of an acute exercise bout at 200 W are all equally strong predictors of endurance exercise performance (20). We therefore chose 4-min lactate levels in the present study for the sake of time efficiency. For comparative purposes, the mean value for the postexercise lactate values in the present study is higher than that reported for a group of well trained subjects who performed an identical exercise bout (6.7 vs. 3.8 mM) (20). The subject group as a whole should be considered as representing a physically untrained sample although the wide range of lactate values suggests a commensurate range in aerobic fitness. Of great interest in the present study was the significant direct relationship between total immersion time and the aerobic fitness level, as reflected by the postexercise lactate. A high level of aerobic fitness implies a high maximal oxygen consumption, and thus a high maximal thermogenic capacity. The relevance of a high capacity for thermogenesis in delaying the onset of hypothermia may be questioned since this capacity is certainly not taxed by cold exposure alone. A review of the literature concerning physical fitness and cold tolerance (17) suggests that there is not a consensus on whether aerobic fitness improves the response to cold water stress. Horvath (17) attributes these conflicting findings, at least in part, to great variations among research groups in experimental design. Yet the results of the present study show a highly significant direct relationship between aerobic fitness level and the total immersion time causing a 1°C decrease in T_{re}. The strength of this relationship is difficult to explain, however it may be due, in part, to our use of blood lactate as an indicator of aerobic fitness as opposed to the usual estimation or determination of maximal oxygen consumption. Such blood lactate related variables reflect several metabolic characteristics of skeletal muscle such as fibre type (19,34), key enzyme activity levels (35), and respiratory capacity (19), which may be more relevant to shivering thermogenesis than maximal oxygen consumption.

A higher aerobic fitness level caused by endurance training increases the reliance of skeletal muscle on fat oxidation as an energy source during exercise (5,23). It is tempting to speculate that high fitness levels and the commensurately high oxidative capacity of skeletal muscle may permit a greater and/or more rapid utilization of the elevated FFA levels induced by the cold, thereby increasing heat production.

Although catecholamine levels were not measured in

TABLE II. BLOOD HORMONE AND SUBSTRATE LEVELS BEFORE AND AFTER A 1°C DECREASE IN RECTAL TEMPERATURE CAUSED BY IMMERSION IN 10°C WATER.

	Glucose mM	Lactate mM	FFA μM	Insulin $\mu U \cdot ml^{-1}$	Glucagon $pg \cdot ml^{-1}$	T_3 $ng \cdot ml^{-1}$	T_4 $\mu g \cdot dl^{-1}$
pre	5.93 ± 1.10	2.01 ± 0.9	757 ± 260	38.3 ± 18.5	226.3 ± 78	1.339 ± 0.17	8.84 ± 1.3
post	6.21 ± 0.62	3.63 ± 1.5	1045 ± 348	26.3 ± 16.8	272.0 ± 91	1.479 ± 0.21	9.56 ± 1.6
n	5	6	8	7	5	7	7
p	0.370	0.030	0.015	0.029	0.111	0.048	0.0009

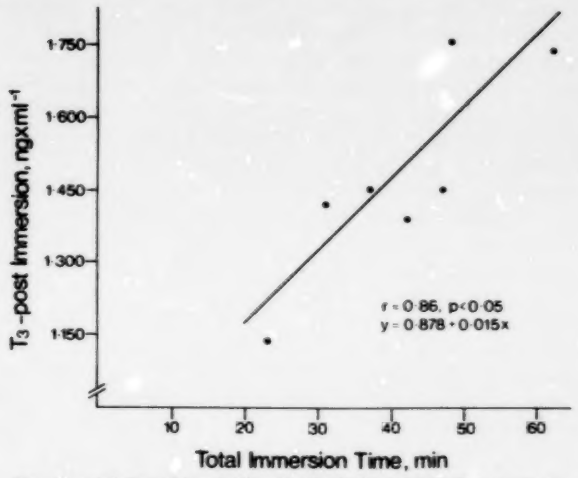

Fig. 3. Relationship of blood triiodothyronine (T_3) concentrations after water immersion to total immersion time required for a 1°C decrease in rectal temperature.

the present study, the effect of fitness on catecholamine sensitivity may also partially explain the observed relationship between fitness and immersion time. Norepinephrine and epinephrine responses to the same relative workload are lower in the trained than in untrained subjects (2,25). This would suggest that endurance training increases the sensitivity to the metabolic effects of catecholamines. The relevance to cold tolerance has been demonstrated in a study where trained rats had higher colonic temperatures and lower catecholamine levels than control animals after 3 h at −20°C (4).

Another factor to consider is that the studies which have examined the effect of physical training on cold tolerance have employed cold air exposure (1,33). The fact that the present study employed a cold water immersion may either further complicate the thermoregulatory mechanisms involved or may actually help to exaggerate and define the relationship between fitness and cold tolerance in light of the greater physiologic stress induced by water as compared to air of the same temperature.

The rate of change in rectal temperature was similar in the present study to that reported previously for subjects immersed in 10°C water wearing only a bathing suit (21). When compared to the data of Johnson *et al.* (21), the maximal increase in metabolic rate was somewhat greater in the present study (3.4 vs 3.0 METS). Both studies, however, show metabolic rates which are over 50% higher than those predicted based on the equations developed by Hayward *et al.* (16). This can be explained since our results are expressed as the maximal increase in metabolic rate above resting values. In contrast, Hayward *et al.* (16) based their predicted metabolic rates on the mean rate calculated between 10–25 min after immersion. One might expect that total immersion time would be related to metabolic heat production during immersion as expressed by oxygen uptake. This was not the case in the present study; however, the timing of gas collection for 3–4 min every 10th min during immersion may have obscured such a relationship.

Confirming many previous reports (eg. 24,28), the insulative effect of body fat in slowing the cooling rate was shown in the present study by the direct relationship between total immersion time and relative body fat content. The BSA, however, was not a significant factor in determining total immersion time.

In the present study circulating FFA increased significantly during the immersion probably as a result of increases in norepinephrine, a potent lipolytic stimulus, which was reported to increase by over threefold after 45 min of immersion in 10°C water (21). The significant increases in lactate have also been observed previously during cold exposure (18,38), although the increases in the present study were much greater. The increased epinephrine secretion during cold water immersion (15,38) coupled with the noticeable shivering, would increase the rate of glycolysis and/or glycogenolysis in skeletal muscle or liver, explaining the increase in blood lactate accumulation. Increasing norepinephrine levels inhibit insulin secretion (14) accounting for the significant decrease in insulin observed in the present study. In conjunction with the decreased insulin levels, glucagon increased in four of five subjects thereby decreasing the insulin/glucagon ratio. Acute cold exposure of rats also decreases this ratio in a similar fashion and it has been suggested that such a change in the insulin/glucagon ratio is a sensitive indicator of thermal stress (9). The blood variable changes observed in the present study should be interpreted with some caution in view of the hemoconcentration reported to occur with cold exposure (18). It is however doubtful that the hemoconcentration induced by cold could explain such large changes (10,18).

It is noteworthy that the changes in the selected blood variables were obviously not related to the change in rectal temperature since all subjects decreased T_{re} by 1°C. These results suggest that measuring rectal temperatures alone will not provide an adequate indication of the degree of physiological stress imposed by cold exposure.

The T_3 concentrations post immersion were related to total immersion time as well as fitness level, the fitter subjects demonstrating higher T_3 levels. This finding contradicts our hypothesis that high fitness levels would diminish the hormonal response to the cold exposure. Since there is a paucity of available literature examining such relationships in humans, results from animal models are reported below although we are aware that extrapolations to humans may be questionable. Hypothyroid rats show a more rapid fall in body temperature upon cold exposure (13) and a markedly lower skeletal muscle oxidative capacity (37) than euthyroid animals. The lower postimmersion T_3 levels in the present study associated with a shorter immersion time and reduced fitness level, may be reflective of a reduced capacity for thermogenesis from skeletal muscle via shivering. In thyroidectomized dogs oxygen consumption during cold water immersion was less than 50% that of euthyroid dogs, although the change in colonic temperature was not different between groups after a 15-min water

immersion (38). In response to cold, catecholamine secretion was increased in the thyroidectomized dogs to a greater extent than in normal animals (38). These increasd catecholamine levels could be interpreted as evidence of a physiological attempt to compensate for the loss of the potentiating effect of thyroid hormones on catecholamines (27,30,38). The correlation between T_3 postimmersion and fitness level must be viewed with caution since it may result from the correlation between immersion time and fitness because immersion time was related to both the T_3 and fitness levels in the present study. Serial blood sampling during the actual immersion would have permitted clarification of whether those subjects in whom the onset of hypothermia was delayed also exhibited earlier and/or greater increases in T_3 or T_4. The relative increases in both T_3 and T_4 were similar in the present study. One can only speculate whether the T_3 increases were due to a greater production by the thyroid gland or a greater peripheral conversion of T_4 to T_3.

In conclusion, during acute cold water immersion in 10°C the length of time for a 1°C decrease in T_{re} was directly related to the endurance fitness level as determined by the blood lactate response to submaximal exercise. Fitness level was not, however, related to the hormonal changes induced by the immersion. A wide variation in the response of metabolic rate and circulating blood hormone and substrate levels to the immersion was evident among subjects although all subjects decreased their T_{re} by 1°C.

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Growth in OTC sales predicted for Europe

NEW YORK—As European governments cut back on public health services, per capita consumption of over-the-counter (OTC) internal medication will rise from $6.23 last year to $7.36 in 1987, according to a new study by Frost & Sullivan, Inc., New York.

The total market in France, Germany, Italy, the UK and Benelux will grow 19% during the period from $1.57 billion to $1.88 billion (all figures in constant 1982 U.S. dollars), says the report, titled "OTC Internal Medication Market in Europe" (#E634).